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Here's the recently-received paper from Meleason.

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# A Simulation Framework for Evaluating the Effect of Riparian Management Strategies on Wood in Streams: An Example Using Oregon's State Forest Riparian Management Regulations

**Mark Meleason, Jeremy Groom, and Liz Dent**


## Abstract

One objective of the Oregon State Forest riparian management strategies is to provide a long-term supply of wood to streams. We explored this objective as a case study by comparing the predicted wood loads from a riparian forest managed in accordance with Northwest Oregon State Forest Management Plan to an unmanaged riparian forest. We obtained riparian tree inventories of plots from an Oregon Department of Forestry's Riparian Function and Stream Temperature Study site. The site's overstory was measured before and after harvest conducted according to the riparian management strategies. We used the pre- and post-treatment data as initial conditions for 200-year growth simulations in the forest growth model PNW Zelig. The forest model results were then used to predict wood volume in the stream from two riparian management scenarios using the model OSU StreamWood. We found that the stream wood volumes were almost identical in the two simulations, suggesting that at least for this particular site, Oregon's state riparian regulations are predicted to provide a long-term supply of wood to streams similar to that in an unmanaged riparian forest.


**Keywords:** large wood, LWD, OSU StreamWood, riparian, management, simulation.

## Introduction

Wood is an integral part of streams in the Pacific Northwest (Bisson et al. 1987). Wood can enter the channel from the adjacent riparian forests, by fluvial transport from upstream, and from upslope sources. Management plans for upslope forests can indirectly influence wood recruitment to streams by increasing geomorphic processes such as landslides and debris flows; however, best management practices seek to minimize these events. In contrast, management of riparian forests can directly influence the long-term supply of wood to streams, and management plans typically include this objective.

Empirical evaluation of riparian management prescriptions is difficult, due in part to the time scales involved to monitor their performance. Also, given the variation in local site conditions such as slope, aspect, forest structure, and temporal pattern in weather and stream flow, it is difficult to generalize the results to a broader scale. In addition, inferences drawn from observational studies are generally limited to the sites and time period of the study.

Simulation modeling is one useful tool to investigate the generalizable effects of riparian forest prescriptions on wood in streams. By

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definition, simulation models are a gross simplification of reality. In fact, the often-quoted phrase by the famous statistician G.E.P. Box "all models are wrong but some are useful" was restated in an expanded version that is worth repeating: "Models of course, are never true, but fortunately it is only necessary that they be useful. For it is usually needful only that they not be grossly wrong" (Box 1979).

The development of simulation models involves many trade-offs, such as the spatial extent (local or regional), the temporal scope (seconds to centuries), and the selection of processes to include or exclude. The design of a model must be closely aligned with the purpose of the model (Mankin et al. 1975). In this light, the OSU StreamWood model was designed to explore the long-term implications of riparian forest management strategies on wood in streams.

In this paper, we use simulation modeling to explore the effectiveness of the Oregon State Forest riparian management strategies (Oregon Department of Forestry 2010) in providing long-term recruitment of wood to streams. Our approach involves isolating the "treatment effect" by comparing a reference simulation to one or more simulated scenarios that differ from the reference by exactly one factor. The two simulations, treatment and reference, are identical in all respects (e.g., stream and initial forest conditions) save for the application of the treatment, which in this application is the riparian management prescription. Although the riparian management prescription is composed of numerous components (e.g., number and width of subzones, harvest protocols, and other rules), it is the overall performance of the riparian treatment that we are evaluating. Indeed, individual actions within the prescription could be evaluated in a similar manner. Our approach involved comparing total wood volume (volume of all logs that intersect at least one bank at a given place and time) from a riparian area with and without the management prescribed for Oregon State Forests. The riparian plots used in this study were measured for Oregon Department of Forestry's Riparian Function and Stream Temperature study (Dent et al. 2008; Groom et al. 2011a, 2011b; referred to hereafter as "RipStream").

## Methods

### Model Description

A brief overview of the model OSU StreamWood is provided here; please refer to Meleason (2001) for details. It is an individual-based stochastic model that operates at an annual time step. Tree recruitment as wood to the stream channel from the riparian forest can be provided by a forest-gap model built within OSU StreamWood, or by importing the results from other forest growth models. In our case, we modified the model to import results from the Pacific Northwest-specific growth models PNW ZELIG (Garman et al. 1992) and ORGANON (Hann 2011). For each simulation year and iteration, each riparian area was populated with trees that died in that simulation interval. Each dead tree had a known species, diameter, and height from the forest model and was randomly assigned a riparian x-y position and tree-fall angle. The riparian area was subdivided into three riparian subzones on each side of the stream. Each subzone was assigned its own width, tree-fall regime (random), and tree mortality file. Trees enter the channel if they intersect the channel given the angle of fall and distance to channel relative to their height. OSU StreamWood subjects trees recruited into stream channels to breakage upon entry. Those logs at least partially within the channel are subjected to in-channel processes of breakage, movement, and decay (fig.1). Minimum log dimension, which can be defined prior to simulation, was set to 1 m in length and 10 cm in diameter. The model runs under a Monte Carlo procedure and results are expressed as a mean and standard deviation or as a frequency distribution of wood for a given year.

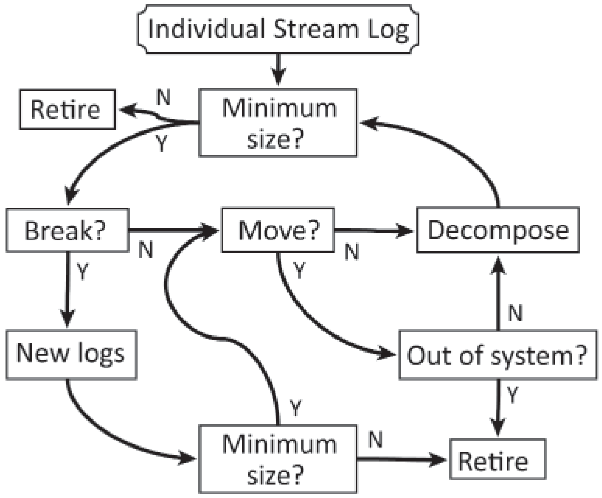


**Figure 1**—Fate of a log within OSU StreamWood. Trees that fall into the channel, which depends on distance to the channel and fall angle, are subjected to tree-entry breakage. For each annual time step, all logs that intersect at least one bank are subjected to a sequence of procedures representing in-channel dynamics. If the log is equal to or greater than the minimum size criteria (user-specified and set to 1-m length and 10-cm diameter for this study), then it is passed to the breakage function, otherwise it is "retired" (removed from further consideration). Breakage is a two-step function: does the log break and if so, then what are the sizes of the new logs? Next, new logs that meet minimum size criteria and logs that did not break during this cycle are subjected to the movement function. Movement is also a two-step process—does the log move and if so, how far? Logs that move out of the system are retired. Finally, logs are "decomposed" and those that meet the minimum size criteria are tallied for the results of this reach for this year. Both breakage and movement are stochastic functions that rely on uniform random numbers to determine their outcome.

## Riparian Sample Sites

The RipStream study was conducted between 2002–2010 and included pre- and post-treatment surveys of a suite of riparian and stream variables at 33 sites in Oregon's Coast Range. One key objective of this study was to assess the performance of state and typical private riparian forest practices on stream temperature in western Oregon (Dent et al 2008; Groom et al. 2011a, 2011b). Another key objective was to determine whether current management approaches were effective in maintaining large wood recruitment to streams.

For the analysis reported here, we selected three sites on Oregon State Forest lands (fig. 2). The proportion of the riparian forest removed (pre- versus post-treatment) was assessed for all three sites (fig. 3), but the simulation of wood recruitment was considered for site 5301 only, which was a second-growth stand from a clearcut with a stand age of 48 years and an active channel width of 5 m. Each site consisted of an upstream reference and a downstream treatment area (fig. 4). Each of these areas contained two riparian plots, one on each side of the stream. Each riparian plot consisted of five sample zones 30 m in length (paralleled to the stream) and 52 m wide, for a total plot area of 0.79 ha (fig. 5). All trees (dbh ≥ 14 cm) were tallied within each zone. In addition, all seedlings (dbh < 14 cm) were tallied by species within six, 42-$m^2$ plots within each sample zone. Vegetation data were collected pre-treatment for all four riparian plots and for the treatment riparian plots in the year following harvest. For site 5301, very little windthrow was noted in the post-treatment survey, so that the standing tree survey reflected the management prescription.

The treatment reaches on the three selected study sites were subjected to harvest according to the Northwest Oregon State Forests Management Plan (Oregon Department of Forestry 2010; table 1), which defines unique management prescriptions for each of three riparian sub-zones. These sub-zones are parallel to the stream channel. Our perpendicularly defined sampling zones did not match these parallel sub-zones, so we reconfigured our riparian data to conform to State Forest harvest strategies. Since our riparian plot data included slope distance of each tree to the stream, we were able to assign trees to one of the three parallel riparian sub-zones defined by slope distance (fig. 5): streambank (0 to 8 m), inner (9 to 30 m), and outer (31 to 52 m) management zones (table 1).

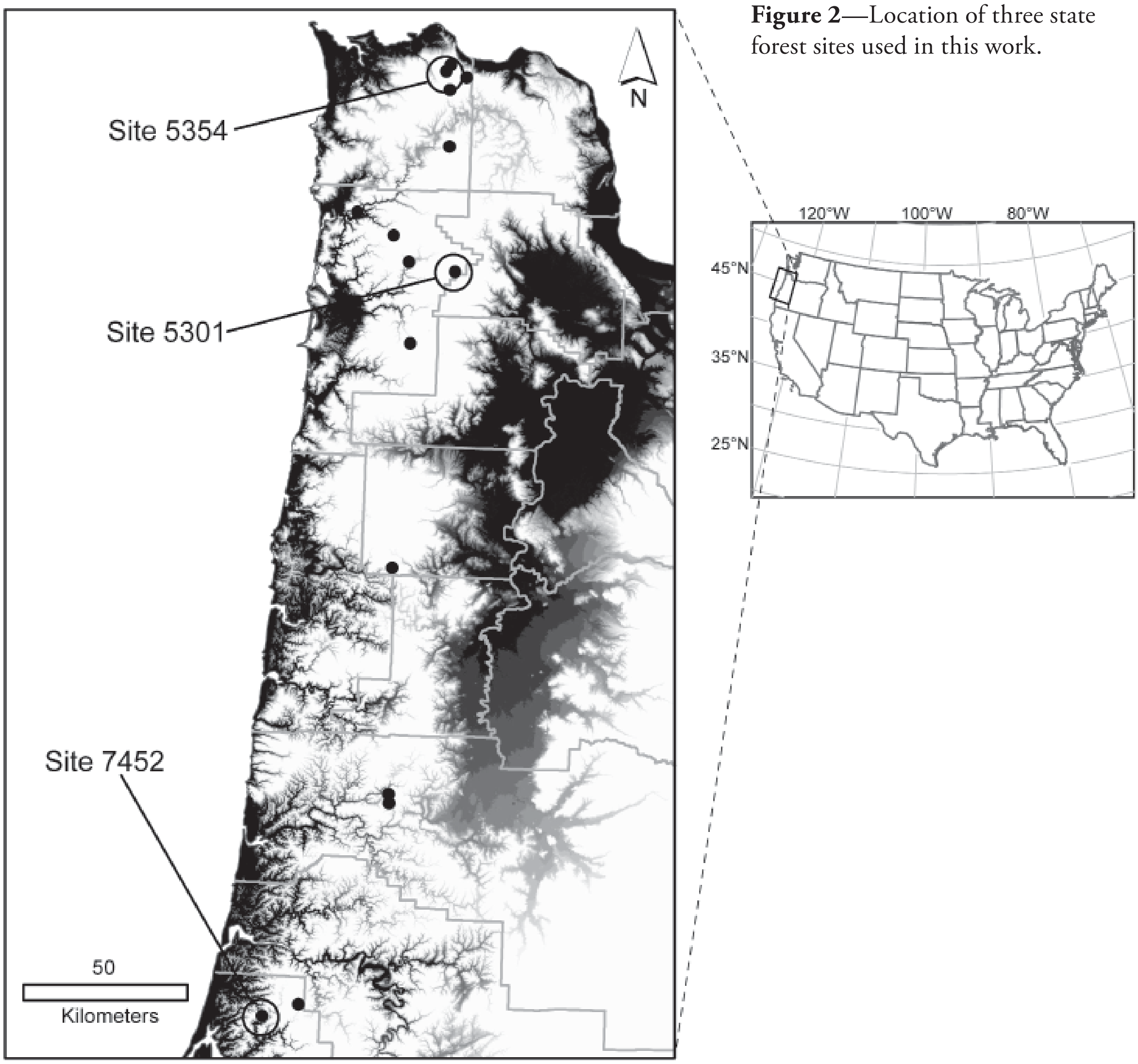


**Figure 2**—Location of three state forest sites used in this work.

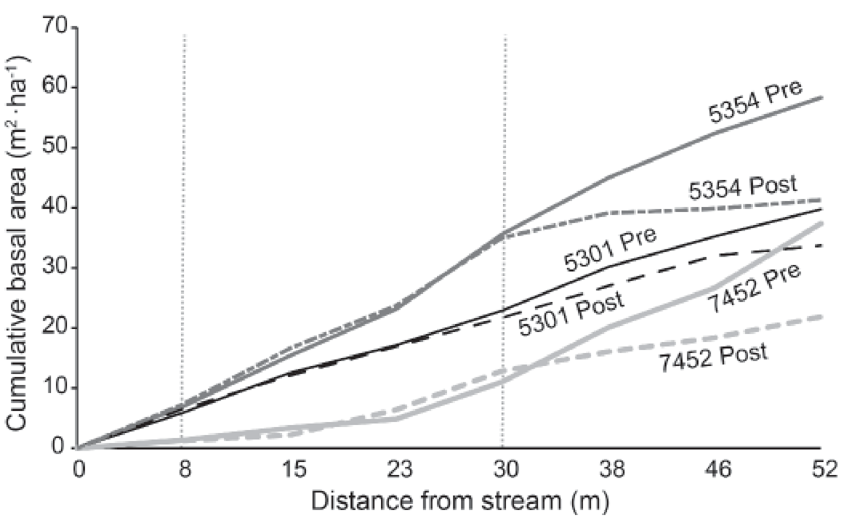


**Figure 3**—Cumulative basal areas by distance from stream for selected state forest harvest sites. The portion of the riparian forest removed through the riparian management strategies is the difference between the pre- (solid line) and post-treatment (dash line) curve for each site. The dark lines at 8 m and 30 m identify the widths of the riparian subzones, each of which have their own management prescriptions (table 1). Of the three sites, 5301 was selected for the simulations reported in the text.

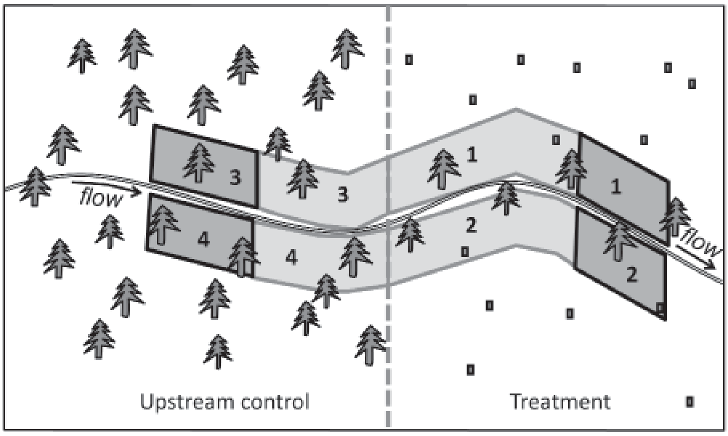


**Figure 4**—Harvest plot layouts and extensions. Each RipStream site had two riparian plots in the reference (upstream; plots 3 & 4) and treatment (downstream; plots 1 & 2) areas. These plots are depicted in dark grey. We extended these plots (light grey) by doubling the data in associated riparian plots to assist in modeling down wood recruitment in these systems. Upstream reference reaches were approximately 330 m in length. Treatment reach lengths varied from 300 m to 1500 m (1460 m for site 5301).

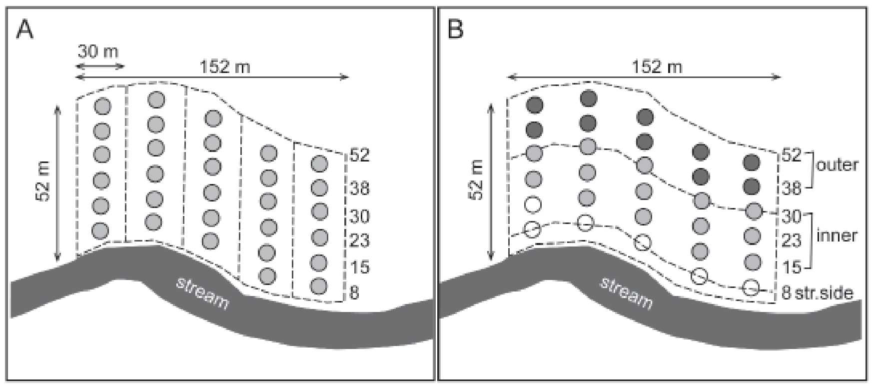


**Figure 5**—Conversion of the RipStream data to initial conditions used in OSU StreamWood. Riparian plot layout in the RipStream study consisted of a 52-m by 150-m riparian zone divided into five 30-m strips. All trees >10 cm dbh were measured. A total of six 0.01-acre (3.7-m diameter) shrub sub-plots were placed within each 30-m strip at 8-m intervals. Each shrub-sub plot included measurement of tree seedlings (<14 cm dbh) and vegetation cover (A) The riparian forest treatment that was applied defined three riparian management prescriptions that differed by sub-zones: 0–8 m, 8–30 m, and 30–52 m (B; table 1).

**Table 1**—Definition of Northwest Oregon State Forest Management Plan (Oregon Department of Forestry 2010) management zones.

| Management zone | Distance to bank | Prescription |
|---|---|---|
| Streambank zone | 0 – 8 m (0 – 25 ft) | No cutting |
| Inner | 8 – 30 m (25 – 100 ft) | Limited entry, manage for mature forest conditions |
| Outer | 30 – 52 m (100 – 170 ft) | Depending on streambank zone conifer density, leave 15–70 conifers / 1000 ft (305 m) |

We created a tree list (with corresponding expansion factors) for each of the three riparian sub-zones per riparian plot including seedlings from the regeneration plots. These riparian sub-plots were then used as the initial conditions for the forest simulations using PNW ZELIG and ORGANON. The dead tree files produced by the forest models were then used as input to OSU StreamWood.

## Simulation of Riparian Forest Growth

OSU StreamWood's prediction of wood in streams depends in part on the input from a forest model. In an effort to increase our confidence in the forest model results (e.g., basal area and tree density through time) as inputs to OSU StreamWood, we compared the two forest models, ORGANON and PNW Zelig. We used the pre-treatment sub-plots for the lower reach as initial conditions for both models. Simulations were for 100 years (100 iterations for PNW Zelig) and the results were compared graphically.

In an effort to assess the consistency between pre- and post-treatment riparian forest simulations, we compared projected basal areas from PNW Zelig. For these runs, which were used in the simulation experiment described below, the simulations were for 100 iterations of 200 years, and we compared the results graphically.

### Influence of Oregon's State Forest Riparian Management Strategies on Long-term Wood Supply

The purpose of our simulations was to assess the effect that the Oregon Forest Practices for state lands have on the long-term supply of wood to streams. Our approach involved comparing stream wood volumes attributed to the pre- and post-treatment (table 1) riparian forests observed at site 5301. We simulated a 4-reach system arranged contiguously, with the two upstream plots as the reference and lower two reaches as the treatment (fig. 4). Reaches were 152 m long (width of the measured plot along the stream, fig. 5) with bankfull widths of 5 m, with no wood in the channel at the beginning of the simulation. The tree mortality output from PNW Zelig was used as input to OSU StreamWood. For the pre-treatment run, we populated the riparian plots with the 1-year pre-harvest mortality data, which consisted of 12 unique data files (3 sub-zones for each riparian plot, 2 riparian plots for each reach type, 2 reach types—treatment and reference). For the treatment simulation, we replaced the treatment reaches with six 1-year post-treatment mortality data files. Both simulations were for 500 iterations of 200 years. We compared the total wood volume in the lower reach between simulations of the pre-treatment and post-treatment riparian forests.

#### Validation

Our primary goal was to isolate the relative impact of a harvest treatment on total wood volume by comparing the results of two simulations that differ by management prescription. A question that arises is whether our predictions could be compared to empirical findings. Validation of our simulation results, as compared to empirical data, cannot be done directly because of the time scales involved. However, our wood volume estimates should be at least reasonable in the broader context when compared to observed wood volume estimates in streams subjected to a similar riparian management regime. To this end, we obtained wood data from the stream habitat surveys collected by Oregon Department of Fish and Wildlife as part of their Aquatic Inventories Project. These data were collected between 1998–2008 using the Aquatic Inventory Protocol (Moore et al. 2008). We obtained data on total wood volume for 142 streams that were within Oregon state forest lands and subjected to the management practice used in our treatment (table 1). We summarized these data graphically, and visually compared them to simulation results. Our intent here was to assess whether the model predictions are similar enough to the observed data to be considered reasonable.

## Results

### PNW Zelig and ORGANON

We visually compared predicted basal areas of standing trees through time from the two forest models for each of the three riparian sub-zones (fig. 6, inner zone not shown). The greatest divergence between the two models was for the streamside zone and least for the outer zone. The inner zone was dominated by *Alnus rubra* (Red Alder, 95 percent of the basal area) and the outer zone was dominated by *Pseudotsuga menziesii* and *Tsuga heterophylla* (Douglas-fir and Western Hemlock, 93 percent of the basal area).

### Riparian Forest Simulations

Prior to treatment, the four plots from site 5301 had a mean basal area of 45 $m^2 \cdot ha^{-1}$, 544 trees per ha, and a mean stand age of 48 years. The riparian treatment reduced basal area by 15 percent in plots 1 and 2 (fig. 3). Pre- and post-treatment simulations for the sub-zones predicted similar stand development, although the pre-treatment had slightly greater basal area and number of trees through the 200-year simulation (fig. 7).

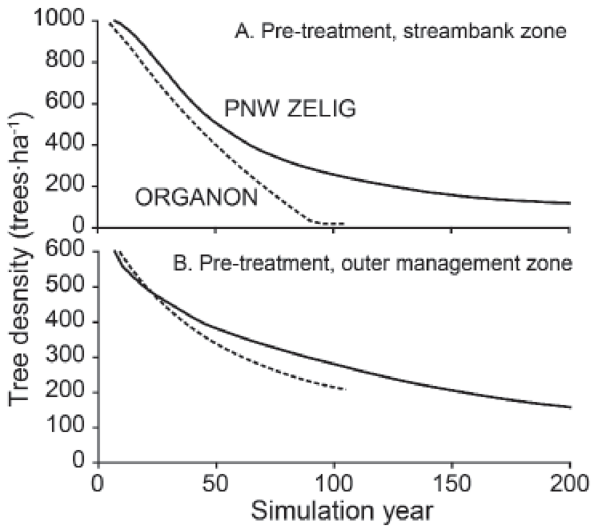


**Figure 6**—Comparison of ORGANON and PNW ZELIG simulations for the streambank and outer pre-treatment riparian sub-zones.

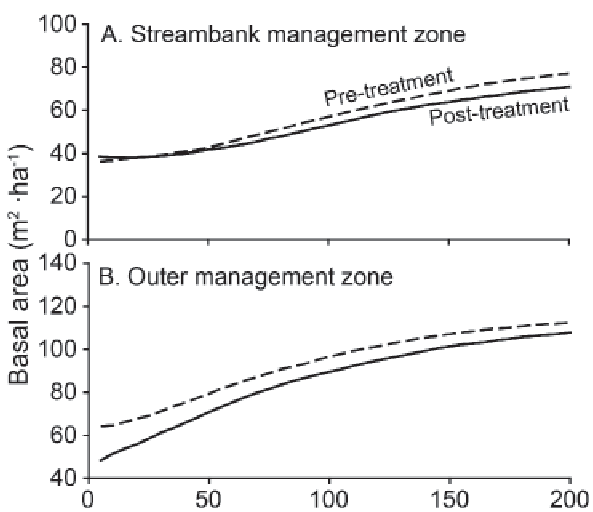


**Figure 7**—PNW ZELIG forest simulations of mean basal area for (a) streambank and (b) outer riparian management zones pre- and post-treatment. All simulations were identical in environmental and site conditions save for the initial tree populations. Tree mortality rates vary through time as the forest matures. Those trees that died are imported into OSU StreamWood where tree entry to the stream is simulated.

## Pre- and Post-treatment Wood Volumes

Mean total wood volume through time was virtually identical between the two riparian forest management scenarios (fig. 8). Mean wood volumes increased through time, as did the variability about the mean. By year 200, the mean wood volume was 98 $m^3 \cdot 100\ m^{-1}$ (standard deviation = 33 $m^3 \cdot 100\ m^{-1}$). The coefficient of variation (standard deviation divided by the mean) ranged from 0.38 early in the simulation to 0.33 by year 200. To further explore the variability within our simulations, we plotted box plots for every 10th year of the simulation (fig. 9). Although the maximum wood volumes increased with simulation year, the minimum was consistently below 20 $m^3 \cdot 100\ m^{-1}$ for the first 100 years and mostly below 30 $m^3 \cdot 100\ m^{-1}$ for the remaining time periods for both the pre- and post-treatment simulations.

### Validation

Although not directly comparable, the model results do appear to be reasonable when compared to the wood volumes from wood surveys in Oregon state forest lands (fig. 11). The median total wood volume was 25 $m^3 \cdot 100\ m^{-1}$ from the field data, which was similar to the median wood volume of the simulated reach (26 $m^3 \cdot 100\ m^{-1}$, fig. 9) at simulation year 60. The greatest difference is the narrow range in wood volumes from the simulations.

## Discussion

The results of our simulation experiment suggest that the state forest management plan strategies could maintain in-stream wood in this stream as compared to an untreated stand. Additional sites would need to be examined to extend this conclusion to other state forests.

Conceptually however, these regulations (table 1) appear adequate to maintain long-term supply of wood to streams. The probability of a tree falling into the stream depends on its height

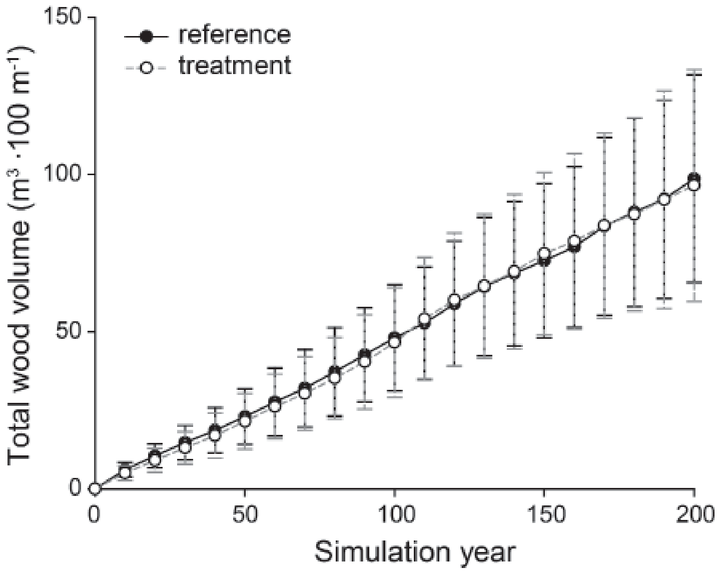


**Figure 8**—Mean total stream wood volume (± 1 standard deviation) for the pre- and post-treatment simulations using OSU StreamWood. All simulations were identical in stream and riparian conditions save for potential dead trees recruited to the channel, which were determined in the forest model simulations. Total wood volume includes the volume of all logs that intersect at least one bank.

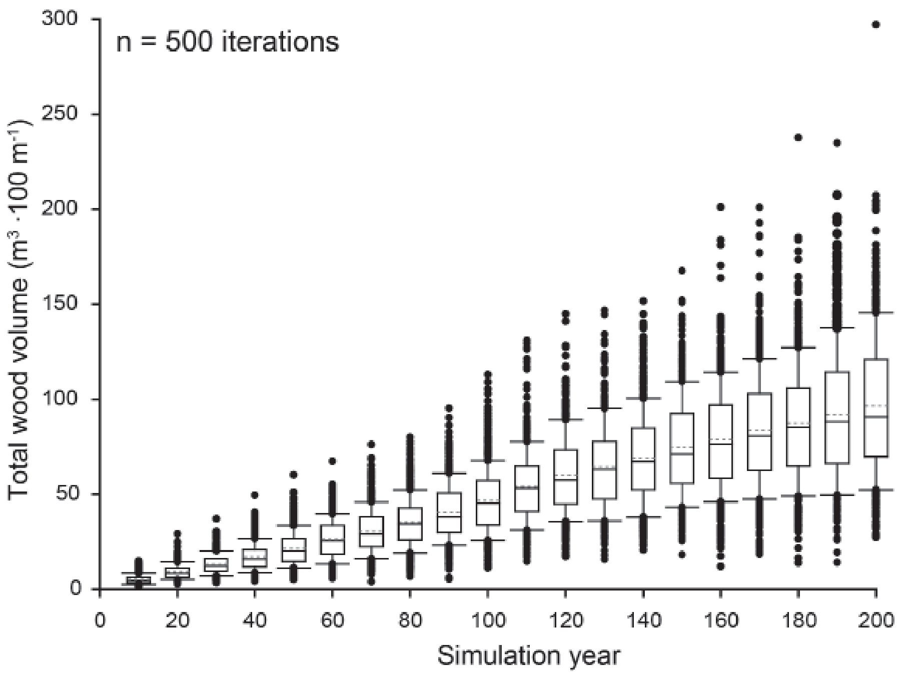


**Figure 9**—Post-treatment Zelig-simulated total wood volume for the downstream-most reach (n = 500 iterations). The lower and upper boundary of the box represent the 25th and 75th percentile, and the whiskers represent the 10th and 90th percentiles. The median (solid line) and mean (dotted line) are represented.

relative to its distance to the stream. For forests <200 years old, approximately 90 percent of the entry events occurred within the first 30 m from streams in both a simulation study (Meleason et al. 2002) and an observational study (McDade et al. 1990). Maximum source distance equals the maximum effective height of the tree species, although the likelihood of a tree falling and entering the stream decreases substantially with distance from the stream. Assuming a completely random tree-fall regime, approximately a third of the wood volume would be estimated to originate within 6 m of the stream and half the total volume would originate within 10 m of the bank for a 200-year-old riparian stand (Meleason et al. 2003). In the state management plan (table 1, Oregon Department of Forestry 2010), the 8-m streambank subzone is a no-cut area and could potentially contribute more than a third of the potential wood recruitment assuming a random tree fall regime.

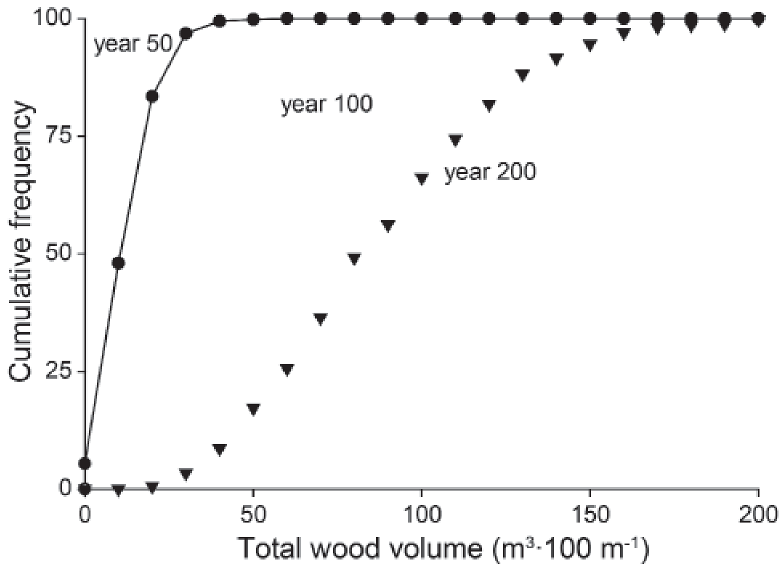


**Figure 10**—Cumulative frequency of post-treatment reach volumes for the lower-most reach for simulation years 50, 100, and 200 (n = 500 iterations). A cumulative frequency of 50 is the median wood load, where half the iterations were greater than and half were less than the wood volume, which corresponds to the median line in fig. 9. The median wood loads went from 20 $m^3 \cdot 100^{-1}$ m at year 50, to 45 $m^3 \cdot 100\ m^{-1}$ at year 100, to 91 $m^3 \cdot 100\ m^{-1}$ at year 200.

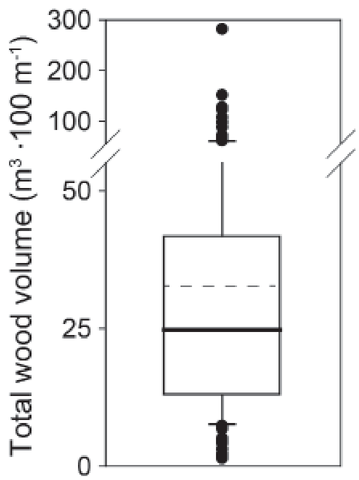


**Figure 11**—Wood survey results for Oregon coastal streams within Oregon State Forests collected by the Oregon Department of Fish and Wildlife (n = 124). The mean total wood volume was 33 $m^3 \cdot 100\ m^{-1}$ and the median was 25 $m^3 \cdot 100\ m^{-1}$. The lower and upper boundary of the box represent the 25th and 75th percentile, and the whiskers represent the 10th and 90th percentiles. The median (solid line) and mean (dotted line) are also represented.

The effectiveness of these regulations in providing a long-term supply of wood to streams would depend on the degree to which the harvest in the inner subzone reduces long-term recruitment. For RipStream site 5301, only 15 percent of the basal area was removed during the treatment and most of this came from the outer riparian subzone (>30 m from the stream bank). This level of harvest appeared to have very little effect on wood recruitment to the steam.

The riparian forests considered here were around 50 years old when the treatment was applied, so very large riparian trees were initially absent. The treatment had very little impact on the forest structure (fig. 3), so the reference and treatment forests that did develop through time were very similar. The performance of these regulations on older riparian forests is a topic worthy of further investigation.

## Model Merits and Management Implications

The use of ORGANON as input to OSU StreamWood to address the question investigated here would be a gross misuse of that model. ORGANON was not designed to grow alder-dominated stands, such as those in our site 5301 or stands >120 years old as we have modeled here (Hann 2011). The purpose of our comparison of forest models was to assess whether they were suitable for our particular application. If the long-term projections of basal area were similar, we could have compared other forest model attributes such as mortality rates, tree size, and species composition. Ultimately, however, the goal was to compare the results of the simulation experiment (e.g., relative performance of the two riparian management scenarios on wood volume in the stream) to see if the selection of forest model influenced the final interpretation. Although ORGANON is a highly versatile model that has proven to be useful for decades, it was not suited for our particular application. Although we are not aware of an ideal forest model for Pacific Northwest riparian forests, PNW Zelig seemed to provide reasonable trajectories of stand development. Since this model has a natural seedling recruitment component, long-term simulations were possible. Other questions, such as those specific to plantation forests, might be better addressed with ORGANON. In OSU StreamWood, each riparian subzone can be associated with a unique forest mortality list, which can be produced by various forest models.

Ecological models are gross simplifications of reality. The usefulness of ecological models, given our understanding of the processes involved and data available, may be seen as "what-if" gaming (Haefner 1996). Although they will always be inadequate and limited, they do provide a means to investigate challenging questions that are virtually impossible otherwise. For example, these results provide one means of investigating the long-term consequences of various riparian management strategies on wood loading in streams. The procedure involved comparing the outcome of two simulations that are identical save for the one aspect under investigation—namely the riparian management prescription. It would be difficult to assess this question empirically, due in part to the time scales involved. In addition, observational studies are specific to the sites considered unless an adequate sample size can be randomly drawn from a population of sites. Even if this were possible, it would be difficult to isolate the treatment effect from additional confounding variables. If the catch phrase for models is "all models are wrong but some are useful", perhaps an appropriate catch phrase for observational studies is that "observational studies are relevant to a time and place; their applicability to another time or place may vary".

This simulation study illustrates that a management prescription applied to a given site has the potential to produce a range of wood volumes in the stream, and this potential range can vary through time (fig. 9). These simulations predicted an overall increase of the range of volumes over the 200-year period. Although the minimum wood volume did increase slightly through time, the majority of this increase was with the maximum wood volumes through time (fig. 9). This suggests that given the same forest structure and stream conditions, there is always a chance that a given prescription can result in a low volume of wood in a given reach. This has a direct implication for riparian forest management targeted at obtaining a desired range of wood volume in streams. A reach with a low volume of wood does not necessarily suggest that the riparian management strategy was inadequate nor does an observed high wood volume necessarily suggest that the prescription is sufficient. Rather, there is a likelihood of obtaining a given volume through time. One way of evaluating the likelihood of a given volume is to develop cumulative probability distributions for a given time period (fig. 10). For example, the simulated results suggest that the management prescription, given these forest and stream conditions, would have a 50 percent chance of obtaining wood loads of 20 $m^3 \cdot 100\ m^{-1}$ at year 50, 45 $m^3 \cdot 100\ m^{-1}$ at year 100, and 91 $m^3 \cdot 100\ m^{-1}$ at year 200 (fig.10). This approach can be used to assess the relative performance of two or more simulated management prescriptions. In this study, the two scenarios—the treatment and reference—produced almost identical results so we have chosen not to include both in figure 10.

## Validation

We concluded from our coarse-level assessment that the simulation distributions of total wood volume compared reasonably with the empirical wood volumes. The greatest difference between the simulation and field data was that the range of wood volumes was narrower in the simulation



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results than in the field estimates. There are several aspects of our approach that did not lend themselves to direct comparison with empirical data. For example, in the simulation we held all stream (e.g., 5-m active channel width) and forest (e.g., site index) conditions constant to isolate the relative performance of the treatment—the goal of this work. The real reaches surveyed varied in both forest and stream conditions as well as other processes that we held constant, such as tree-fall regime and contribution of wood from upslope sources. Many of these factors can be addressed within the modeling framework (e.g., directional tree-fall, influence of key pieces on log mobility in larger channels) provided they are necessary for addressing the particular question under investigation.

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